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Clinical Studies

Pelvic parameters directly influence ideal S2 alar-iliac (S2AI) screw trajectory ☆

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A R T I C L E I N F O

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A B S T R A C T

Background: The utilization of the S2 Alar-Iliac (S2AI) screw provides an optimal method of spinopelvic fixation. The free-hand placement of these screws obviates the use of intra-operative fluoroscopy and relies heavily on sacropelvic anatomy; variations of this anatomy could alter the ideal screw trajectory. The S2AI corridor is near several neurovascular structures, thus an accurate trajectory is critical. The reported angles of trajectory vary within the literature and a paucity of data exists on how patient morphometry influences ideal screw trajectory. We sought to examine the relationship between ideal screw trajectory and pelvic parameters.

Methods: The records of 99 consecutive patients with degenerative thoracolumbar pathology were reviewed and pelvic parameters including sacral slope, pelvic tilt, and pelvic incidence were measured with preoperative standing radiographs. Using 3-dimensional computed tomography (CT) reconstructions, an ideal S2AI trajectory was defined and anteroposterior (horizontal) and cephalocaudal (sagittal) angles were recorded.

Results: Pelvic tilt was found to have a moderate inverse correlation with cephalocaudal screw trajectory (r=-0.467, p-value=0.006). Pelvic incidence and sacral slope had weaker correlations with cephalocaudal screw angle. In subgroup analysis, patients with high pelvic tilt (>20°) had a significantly lower cephalocaudal screw trajectory (24.9 ± 3.7° versus 29.8 ± 2.8°, p-value=<0.001) compared to those with a normal pelvic tilt (≤20°).

Conclusions: This study found an inverse relationship between pelvic tilt and cephalocaudal S2AI screw trajectory. Therefore, the sagittal angle of insertion becomes increasingly more perpendicular to the floor (less caudally orientated) as pelvic tilt increases in reference to a patient positioned prone on an operating table parallel to the floor. This may bolster safety and efficacy when utilizing the free-hand technique for placement of the S2AI screw as it allows the surgeon to plan a more ideal trajectory by accounting for pelvic parameters.

Introduction

Spinopelvic instrumentation is an important tool in the armamentarium of the spine surgeon; this modality aids in the treatment of scoliosis, in fusions of osteoporotic degenerative disease, and in the reduction of high-grade spondylolisthesis and spinopelvic dissociation [1–4]. The addition of pelvic fixation may increase the overall biomechanical integrity and decrease failure under load, especially with long constructs [5,6].

The S2 Alar-Iliac (S2AI) screw is a recent advancement in spinopelvic fixation [7]. First described by Sponseller and Kebaish in the setting of pediatric [8] and adult deformity [9], this modality offers several advantages including tricortical purchase [10], ease of rod placement [11], limited sacropelvic dissection [11], and decreased screw prominence [10–12]. Decreased rates of surgical site infection, reoperation, and wound dehiscence have been reported when compared to spinopelvic fixation utilizing the iliac screw [10,12]. Traditionally, the screw is placed under fluoroscopy [11], however placement under stereotactic navigation [13] or with robotic guidance [14] has also been described. More recently, the free-hand technique, which precludes the need for intraoperative fluoroscopy by relying on the surrounding sacropelvic anatomy, was introduced [15,16]. Shillingford, Laratta, Lenke, and col-

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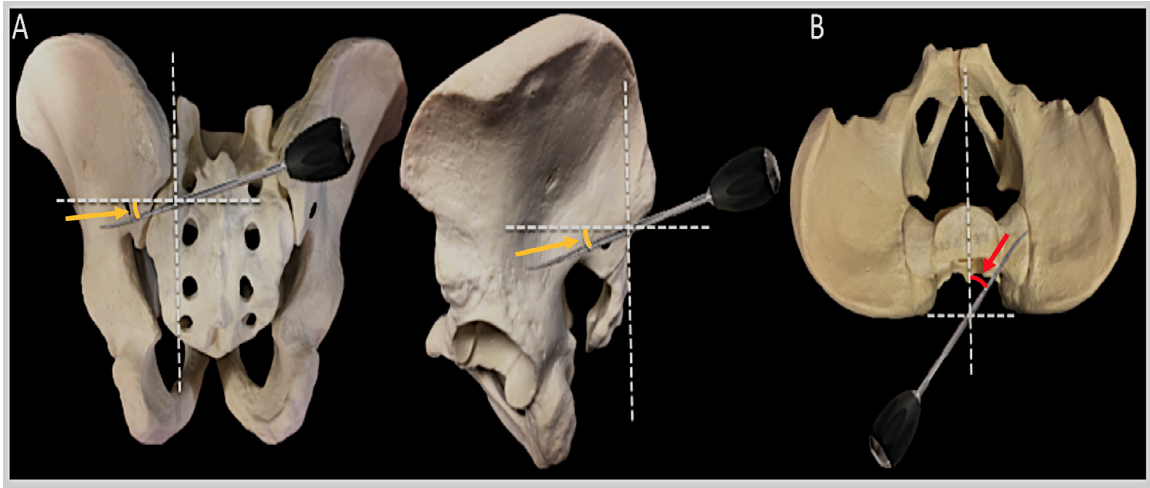

Fig. 1. Model for S2AI placement and trajectory. Panel A is a depiction of the cephalocaudal angle as demonstrated by the orientation of the probe. The cephalocaudal angle is the yellow arc at the end of the arrow. Panel B is a depiction of the anteroposterior angle demonstrated by the orientation of the probe. The anteroposterior angle is the red arc at the end of the arrow.

leagues demonstrated the free-hand technique as safe and reliable for placing S2AI screws in adults with spinal deformity [15,17].

The S2AI starting point has been well-described as midway between the S1 and S2 foramina and at their lateral border [11]. However, screw angulation and trajectory rely on patient-specific anatomic landmarks [15,18]. It is essential for the anteroposterior trajectory to avoid the pelvis proper anteromedially, and for the cephalocaudal trajectory to avoid the sciatic notch inferiorly; Fig. 1 demonstrates the insertion point and screw trajectory. (Fig. 1) Although the anteroposterior trajectory is typically obtained by dropping the hand until the gearshift rests on the sacral spinous processes and the cephalocaudal trajectory is obtained by aiming perpendicular to the sacral laminar slope [18] or just distal to the PSIS (posterior superior iliac spine) [15], these angulations may vary significantly from patient to patient.

Patients with spinal deformity, a population in which the S2AI screw is frequently utilized, have significant spinopelvic compensatory changes which may alter the surgeon's planned S2AI trajectory [19–25]. Therefore, the consideration of pelvic parameters may aid in the safe free-hand placement of these screws. To date, there has been no published literature on what role pelvic parameters play in determining the accuracy of S2AI screw placement. This study sought to evaluate the relationship of pelvic parameters and ideal S2AI screw trajectory.

Methods

In this single center, retrospective series spanning 2015 to 2016, the medical records and preoperative computed tomography (CT) scans of 99 consecutive patients with degenerative thoracolumbar pathology were reviewed by two independent investigators (J.L.L. and J.N.S.). The inclusion criteria were as follows: patients > 18 years of age, degenerative thoracolumbar pathology, and the presence of both lumbar CT scan and upright radiographs. Thoracolumbar pathology included spondylolisthesis, degenerative scoliosis, and lumbar spondylosis/stenosis. Patients with neoplastic processes of primary or metastatic etiology were excluded, as were patients with prior thoracolumbar surgery. The study protocol was reviewed and approved by our University's Institutional Review Board (IRB). Preoperative standing radiographs were assessed to measure pelvic parameters including sacral slope, pelvic tilt, and pelvic incidence as defined in previous studies [26,27]. A 2-dimensional rendering of these pelvic parameters can be seen in Fig. 2. (Fig. 2) Three-dimensional interactive viewing and manipulation of the CT images with VitreaCore software (ViTAL version 6.7.6, A Toshiba Medical Systems Group Company) allowed for creation of an "ideal" S2AI trajectory.

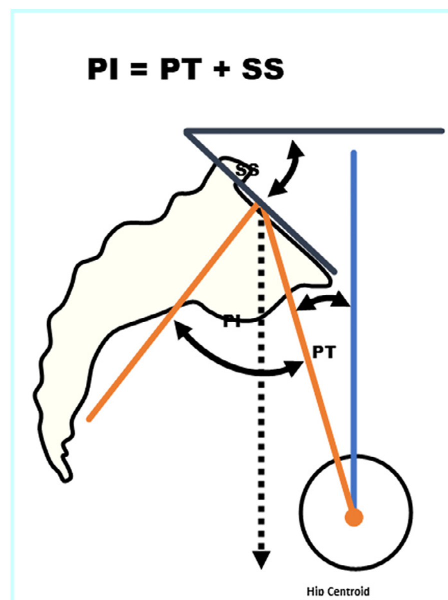

Fig. 2. Depiction of the pelvic parameters pelvic incidence (PI), sacral slope (SS), and pelvic tilt (PT). SS is the angle between the gray lines which depict the direction of the sacral plateau and the horizontal plane. PI is the angle between the orange lines which from left to right represent the plane perpendicular to the sacral plateau at its midpoint and the sagittal pelvic thickness. PT is the angle between the orange line representing sagittal pelvic thickness and the blue line which is orientated perpendicular to the horizontal plane.

An ideal S2AI trajectory was defined as the starting point midway between the S1 and S2 foramina with a screw axis orientated cephalocaudally toward the anterior-inferior iliac spine (AIIS) within the sagittal plane. In the axial plane, the trajectory started at the lateral aspect of the S1 and S2 foramina and was directed through the narrowest portion of the ilium. Anteroposterior (horizontal) and cephalocaudal (sagittal) angles were recorded.

Statistical analysis

SPSS Statistics v24.0 (IBM Corp, Armonk NY) was utilized to analyze the data. Pearson correlation coefficient (r) and independent Student's

Table 1
Patient characteristics and average ideal S2AI screw insertion angles.

Patient Characteristics	
Total Number of Patients	99
Mean Age, years	62.4 ± 12.5
Female Patients (%)	42 (42.4)
Average Ideal Screw Insertion Angles	
Sagittal Angle	27.3 ± 4.1°
Horizontal Angle	35.9 ± 3.9°

Table 2
Correlation of sagittal screw angle to pelvic parameters.

Sagittal Screw Angle Correlation to Pelvic Parameters		
Pelvic Parameter	Pearson Correlation (r)	p-Value
Pelvic Tilt	−0.467	**0.006**
Sacral Slope	0.212	0.236
Pelvic Incidence	−0.140	0.437

T-test were used to demonstrate correlation and test for significance respectively in the values of pelvic tilt, sacral slope, and pelvic incidence versus cephalocaudal screw trajectory. Further subgroup analysis was attained where groups of high (>20°) and low (≤20°) pelvic tilt were compared to cephalocaudal and anteroposterior angle utilizing an independent Student's T-test. Findings were considered significant when a p-value was found to be <0.05.

Results

Demographical data

A total of 99 patients were included in this study, of this number, 42 (42.4%) were female. The mean age was 62.4 ± 12.5 years.

Imaging data

The average cephalocaudal angle measured 27.3 ± 4.1° in the sagittal plane. The average anteroposterior angle measured in the axial plane in respect to the PSIS was 35.9 ± 3.9° (Table 1).

Statistical results

Pelvic tilt was found to have a statically significant, moderate inverse correlation with cephalocaudal screw trajectory (r=−0.467, p-value= 0.006). Sacral slope demonstrated a weak direct correlation with cephalocaudal screw angle (r=−0.212, p-value 0.236), while pelvic incidence was weakly correlated to cephalocaudal screw angle inversely (r=−0.140, p-value=0.437). (Table 2) Graphical representation of pelvic tilt, sacral slope, and pelvic incidence versus cephalocaudal screw angle in a linear regression model can be seen in Figs. 3–5, respectively.

Subgroup analysis

Patients grouped into a category of high pelvic tilt (>20°) were shown to have a statistically significant lower cephalocaudal angulation of screw trajectory when compared to patients with a pelvic tilt of ≤20° (24.9 ± 3.7° versus 29.8 ± 2.8° respectively, p-value <0.001). (Table 3) A radiographic depiction of the ideal projected S2AI trajectory in patients with pelvic tilts of 30° and 10° can be seen in Fig. 6.

Discussion

The free-hand placement of the S2AI screw in the setting of adult spinal deformity was first described by Shillingford, Laratta, Lenke, and colleagues [15]. Patients with sagittal deformity demonstrate a cascade of compensatory mechanisms to maintain an upright posture, including increased pelvic tilt (pelvic retroversion) and decreased sacral slope [19–25]. Variations of sacropelvic anatomy could affect the ideal screw trajectory and an accurate trajectory is critical as the S2AI corridor traverses near several vital neurovascular structures [28,29]. Although the placement of these screws has been demonstrated to be safe and effective without fluoroscopic guidance and equally as safe as robotic assisted placement [15,17], the relationship of pelvic parameters and screw trajectory had yet to be studied.

The surrounding sacropelvic anatomy predicates the placement and path of the S2AI screw when using the free-hand technique [15,16,18]. The starting point is described as the midpoint between the S1 and S2 foramina and 3 mm lateral to the sacral crest while directing the screw to a point just superior to the posterior distal edge of the PSIS and perpendicular to the lateral sacral crest [15]. The resultant angles of trajectory have been reported in several papers, ranging from 27.5° to 48.8° and 30.8° to 67.3°in the sagittal and horizantal planes in one literature review including seven studies [30]. Park et al. noted an average anteroposterior angle of 32.0 ± 1.8° and a cephalocaudal angle of 17.3 ± 5.4° amongst 4 cadaveric specimens without deformity [16]. Shillingford and colleagues reported an average cephalocaudal angle of 24.2 ± 10° and an anteroposterior angle of 39.3 ± 8.2° [15]. Our study found a cephalocaudal angle of 27.3 ± 4.1° and an anteroposterior angle of 35.9 ± 3.9° While the literature reports a relatively large range regarding the angles of trajectory, there is a paucity of literature regarding the impact of patient morphometry upon the ideal S2AI trajectory.

Other variations of ideal S2AI screw trajectory have been reported in the literature. Work by Zhu et al. within the Chinese population demonstrated a significantly greater cephalocaudal trajectory within females, concluding the trajectory should be 5° more caudal than the recommended 30° in males of Chinese descent [31]. Li et al. concurred in their own study, reporting an additional 5° of caudal angulation within the sagittal plane was necessary in females versus males undergoing S2AI fixation [32]. With the free-hand technique in an adult deformity population, a greater anteroposterior angle was noted amongst screws with posterior cortical breach (44.4 ± 6.8°) compared to those without cortical breach (38.9 ± 8.2°) [15]. Our study demonstrated a significant inverse correlation where with increasing pelvic tilt, the ideal S2AI trajectory became less caudally angled. This relationship may be of importance within the adult spinal deformity population. These patients have higher pelvic tilts than asymptomatic volunteers [24,25] and are a group in which the S2AI screw is used frequently. Our findings suggest a less caudally angled trajectory is ideal amongst this group of patients.

An ideal trajectory of the S2AI screw is vital as inaccurate placement may cause cortical breach resulting in risk of iatrogenic injury. Anatomical studies have elucidated the proximate relationship of the screw corridor and several soft tissue structures within the pelvis. These vital structures include the abdominal and pelvic viscera anteromedially, the internal iliac vessels, obturator nerve, lumbosacral trunk, and sacral plexus medially [28,29]. Immediately inferior of the screw corridor lies the sciatic notch which contains a plethora of structures including the superior gluteal neurovasculature just superior to the piriformis muscle, sciatic nerve, internal pudendal vessels, and pudendal nerve [33]. A trajectory too caudal risks violating the sciatic notch potentially resulting in devasting complications; this underscores the importance of our data demonstrating that a less caudal S2AI screw trajectory is ideal in patients with a high pelvic tilt. Furthermore, the area that traverses immediately superior to the sciatic notch has purchase through the dense cortical bone of this area and yields an increased pullout strength [33]; therefore, an angle not caudal enough in patients with a lower pelvic tilt would miss this area of denser bone. Thus, the consideration of pelvic parameters may augment both the safety and efficacy of free-hand S2AI screw placement.

In consideration of these findings, several limitations exist within this study. First and foremost, the retrospective nature promotes only the

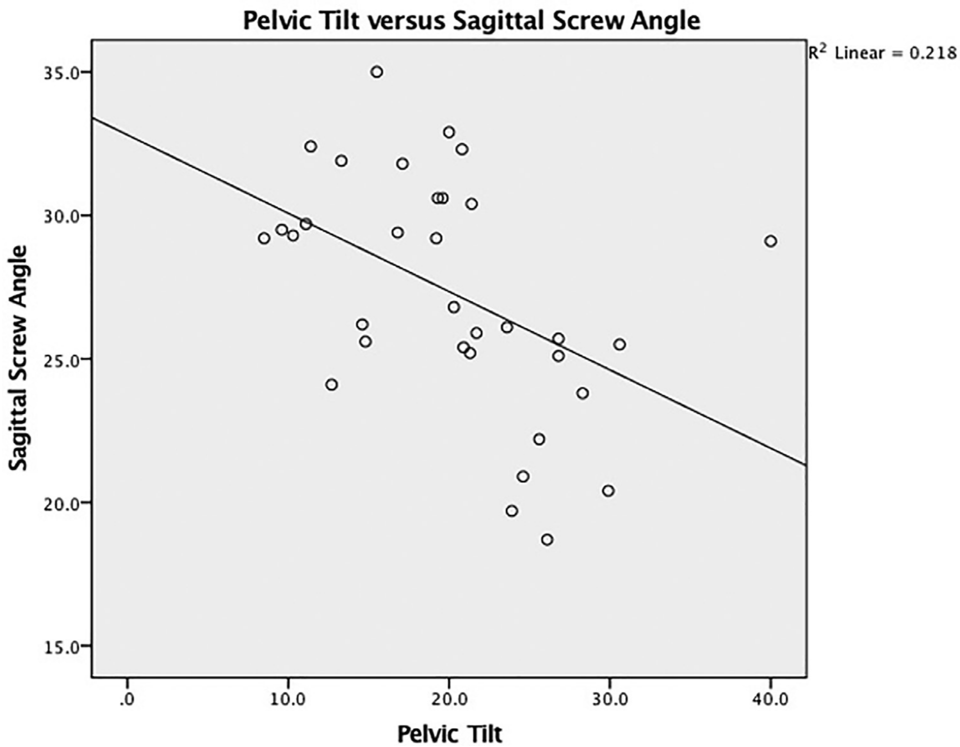

Fig. 3. Linear regression and data plot of sagittal screw angle in respect to pelvic tilt.

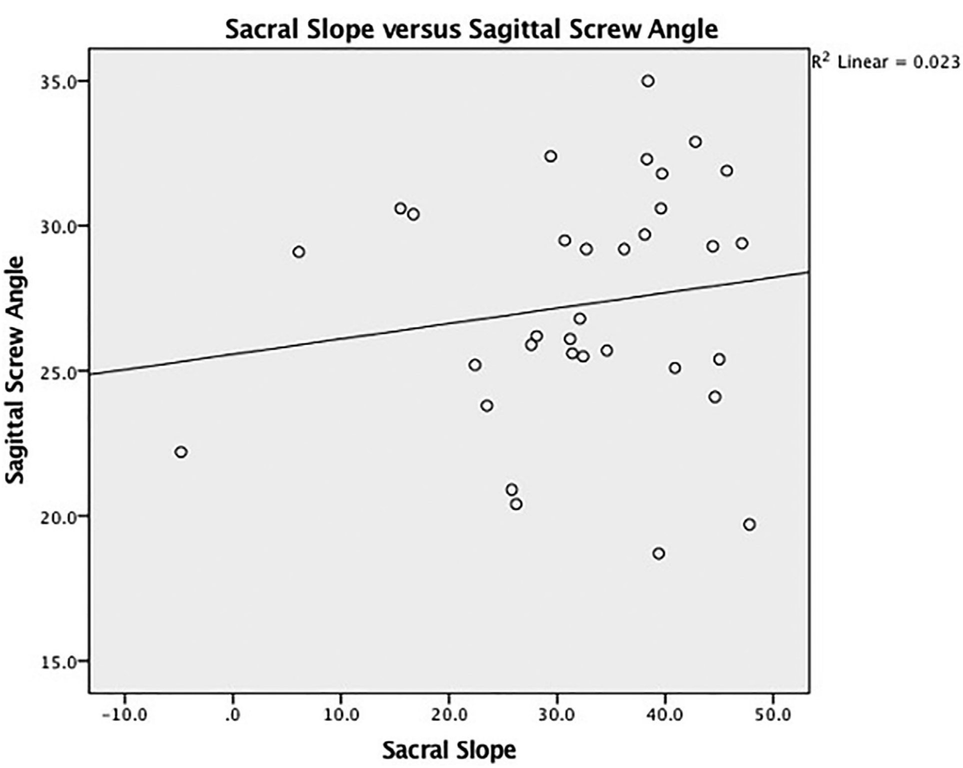

Fig. 4. Linear regression and data plot of sagittal screw angle in respect to sacral slope.

Table 3
Subgroup analysis of patients with low and high pelvic tilt.

High versus Low Pelvic Tilt	Low Pelvic Tilt (≤20°)	High Pelvic Tilt (>20°)	p-Value
Number of patients (%)	48 (48.5)	51 (51.5)	
Sagittal Angle	29.8 ± 2.8°	24.9 ± 3.7°	**<0.001**
Horizontal Angle	36.2 ± 4.9°	35.7 ± 2.8°	0.746

Significant p-values (p<0.05) are bolded.

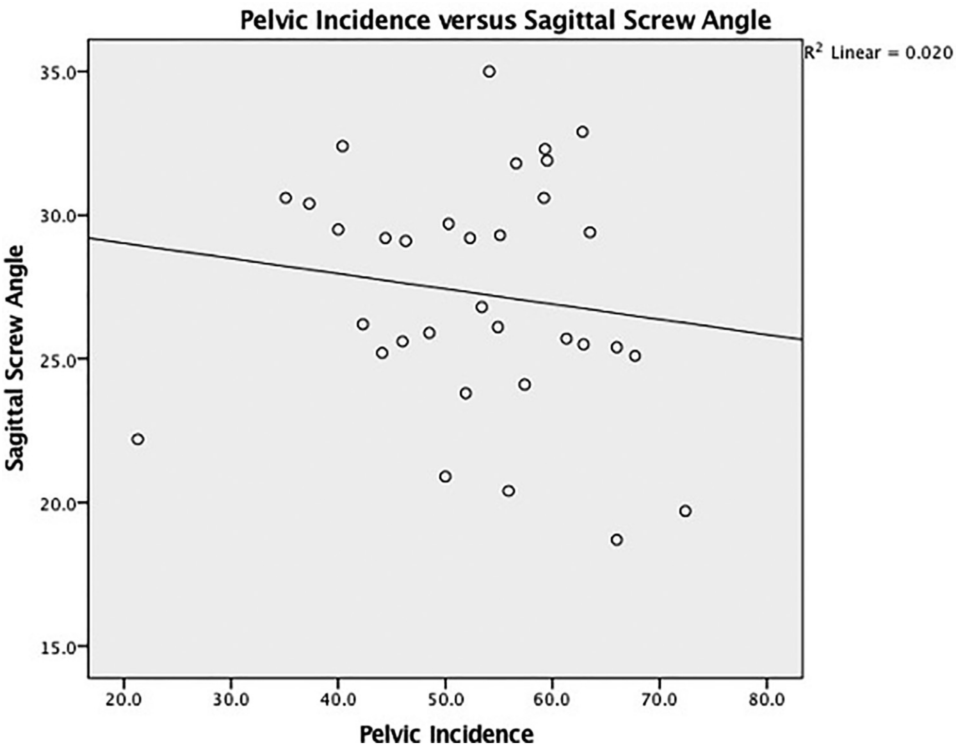

Fig. 5. Linear regression and data plot of sagittal screw angle in respect to pelvic incidence.

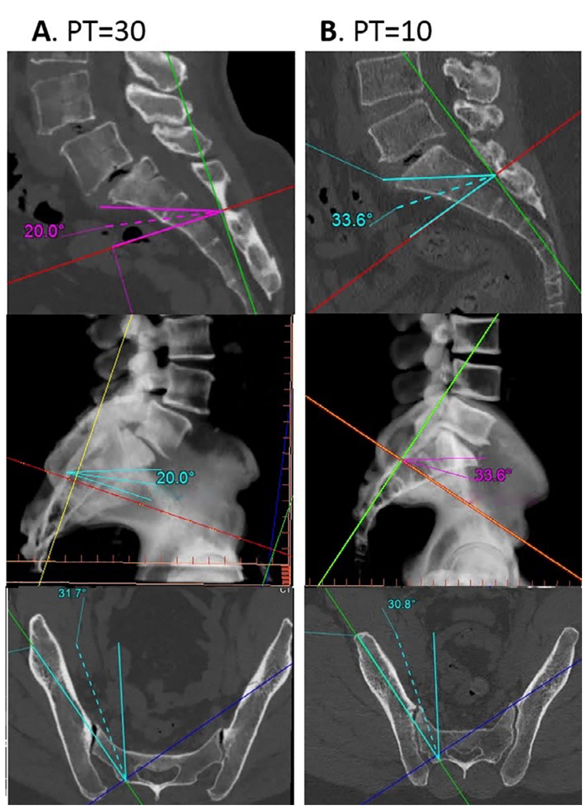

Fig. 6. Radiographic comparison of the ideal S2AI screw trajectory in a patient with a pelvic tilt (PT) of 30° and a patient with a PT of 10° The first four images depict cephalocaudal trajectory delineated by the listed angles, 20° on side A and 33.6° on side B. The red line represents ideal S2AI trajectory and demonstrates a less caudal angle with increased PT. The bottom two images depict anteroposterior trajectory with angles of 31.7° and 30.8° The green/teal line represents the ideal S2AI trajectory in the anteroposterior dimension.

hypothesis that pelvic parameters influence S2AI screw trajectory. Also, the limited sample size of 99 patients may decrease the generalizability of the results. A prospective design comparing S2AI screw trajectory amongst cohorts stratified by pelvic parameters would further support the findings of our study.

Conclusions

This study found a statistically significant inverse correlation between pelvic tilt and the ideal cephalocaudal trajectory of the S2AI screw. The free-hand technique allows for the surgeon to safely place S2AI screws without fluoroscopy, but the trajectory relies heavily on the surrounding sacropelvic anatomy. Our study proposes that as the pelvic tilt increases (as measured on preoperative standing radiographs), the angle of S2AI insertion becomes increasingly more perpendicular to the floor (less caudal) and as pelvic tilt decreases, the angle becomes increasingly more parallel to the floor (more caudal) in reference to the patient lying on a table prone and parallel to the floor. This translates to the surgeon holding the gearshift probe more upright in patients with high pelvic tilt and dropping his or her hand toward the head of the patient to obtain a more caudal angle in patients with low pelvic tilt. Should this angle be too caudal, the sciatic notch may inadvertently be violated potentially resulting in iatrogenic injury; an angle too cephalad may decrease screw pull-out strength by missing the dense cortical bone just superior of the sciatic notch. Therefore, the consideration of pelvic parameters may bolster the safety and efficacy of S2AI screw placement using the free-hand technique.

Disclosures

This study received no means of outside funding. There are no known conflicts of interest amongst the authors that pertain to the contents of this manuscript. A full disclosure statement of each author is accompanied in this submission.

Declaration of Competing Interest

None.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.xnsj.2020.100014.

References

[1] Allen BL Jr, Ferguson RL. The Galveston experience with L-rod instrumentation for adolescent idiopathic scoliosis. Clin Orthop Relat Res 1988;229:59–69.
[2] Jain A, Hassanzadeh H, Strike SA, Menga EN, Sponseller PD, Kebaish KM. Pelvic fixation in adult and pediatric spine surgery: historical perspective, indications, and techniques: AAOS exhibit selection. J Bone Joint Surg Am 2015;97(18):1521–8.
[3] Kebaish KM. Sacropelvic fixation: techniques and complications. Spine (Phila Pa 1976) 2010;35(25):2245–51.
[4] Shen FH, Mason JR, Shimer AL, Arlet VM. Pelvic fixation for adult scoliosis. Eur Spine J 2013;22(Suppl 2):S265–75.
[5] Lebwohl NH, Cunningham BW, Dmitriev A, et al. Biomechanical comparison of lumbosacral fixation techniques in a calf spine model. Spine (Phila Pa 1976) 2002;27(21):2312–20.
[6] McCord DH, Cunningham BW, Shono Y, Myers JJ, McAfee PC. Biomechanical analysis of lumbosacral fixation. Spine (Phila Pa 1976) 1992;17(8 Suppl):S235–43.
[7] Sponseller PD. The S2 portal to the ilium. Semin Spine Surg 2007;2:83–7.
[8] Sponseller PD, Zimmerman RM, Ko PS, et al. Low profile pelvic fixation with the sacral alar iliac technique in the pediatric population improves results at two-year minimum follow-up. Spine (Phila Pa 1976) 2010;35(20):1887–92.
[9] Kebaish KM, Gunne AP, Mohamed AS, et al. A new low profile sacro-pelvic fixation using s2 alar iliac (S2AI) screws in adult deformity fusion to the sacrum: a prospective study with minimum two year follow-up 4; September 23–26, 2009; San Antonio, Texas 4th annual meeting and course of the scoliosis research society San Antonio, Texas; 2009. 2009/09/23.
[10] Ishida W, Elder BD, Holmes C, et al. S2-alar-iliac screws are associated with lower rate of symptomatic screw prominence than iliac screws: radiographic analysis of minimal distance from screw head to skin. World Neurosurg 2016;93:253–60.
[11] Chang TL, Sponseller PD, Kebaish KM, Fishman EK. Low profile pelvic fixation: anatomic parameters for sacral alar-iliac fixation versus traditional iliac fixation. Spine (Phila Pa 1976) 2009;34(5):436–40.
[12] Elder BD, Ishida W, Lo SL, et al. Use of S2-alar-iliac screws associated with less complications than iliac screws in adult lumbosacropelvic fixation. Spine (Phila Pa 1976) 2017;42(3):E142–E1E9.
[13] Ray WZ, Ravindra VM, Schmidt MH, Dailey AT. Stereotactic navigation with the O-arm for placement of S-2 alar iliac screws in pelvic lumbar fixation. J Neurosurg Spine 2013;18(5):490–5.
[14] Bederman SS, Hahn P, Colin V, Kiester PD, Bhatia NN. Robotic guidance for s2-alar-iliac screws in spinal deformity correction. Clin Spine Surg 2017;30(1):E49–53.
[15] Shillingford JN, Laratta JL, Tan LA, et al. The free-hand technique for S2-alar-iliac screw placement: a safe and effective method for sacropelvic fixation in adult spinal deformity. J Bone Joint Surg Am 2018;100(4):334–42.
[16] Park JH, Hyun SJ, Kim KJ, Jahng TA. Free hand insertion technique of S2 sacral alar-iliac screws for spino-pelvic fixation: technical note, acadaveric study. J Korean Neurosurg Soc. 2015;58(6):578–81.
[17] Shillingford JN, Laratta JL, Park PJ, et al. Human versus robot: a propensity-matched analysis of the accuracy of free hand versus robotic guidance for placement of S2 alar-iliac (S2AI) screws. Spine (Phila Pa 1976) 2018;43(21):E1297–EE304.
[18] Lin JD, Tan LA, Wei C, et al. The posterior superior iliac spine and sacral laminar slope: key anatomical landmarks for freehand S2-alar-iliac screw placement. J Neurosurg Spine 2018;29(4):429–34.
[19] Chaleat-Valayer E, Mac-Thiong JM, Paquet J, Berthonnaud E, Siani F, Roussouly P. Sagittal spino-pelvic alignment in chronic low back pain. Eur Spine J 2011;20(Suppl 5):634–40.
[20] Cheung JPY. The importance of sagittal balance in adult scoliosis surgery. Ann Transl Med 2020;8(2):35.
[21] Rajnics P, Templier A, Skalli W, Lavaste F, Illes T. The association of sagittal spinal and pelvic parameters in asymptomatic persons and patients with isthmic spondylolisthesis. J Spinal Disord Tech 2002;15(1):24–30.
[22] Roussouly P, Pinheiro-Franco JL. Biomechanical analysis of the spino-pelvic organization and adaptation in pathology. Eur Spine J 2011;20(Suppl 5):609–18.
[23] Labelle H, Roussouly P, Berthonnaud E, et al. Spondylolisthesis, pelvic incidence, and spinopelvic balance: a correlation study. Spine (Phila Pa 1976) 2004;29(18):2049–54.
[24] Vialle R, Levassor N, Rillardon L, Templier A, Skalli W, Guigui P. Radiographic analysis of the sagittal alignment and balance of the spine in asymptomatic subjects. J Bone Joint Surg Am 2005;87(2):260–7.
[25] Lafage V, Schwab F, Patel A, Hawkinson N, Farcy JP. Pelvic tilt and truncal inclination: two key radiographic parameters in the setting of adults with spinal deformity. Spine (Phila Pa 1976) 2009;34(17):E599–606.
[26] Legaye J, Duval-Beaupere G, Hecquet J, Marty C. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J 1998;7(2):99–103.
[27] Duval-Beaupere G, Schmidt C, Cosson P. A Barycentremetric study of the sagittal shape of spine and pelvis: the conditions required for an economic standing position. Ann Biomed Eng 1992;20(4):451–62.
[28] Abdul-Jabbar A, Yilmaz E, Iwanaga J, et al. Neurovascular Relationships of S2AI Screw Placement: anatomic Study. World Neurosurg 2018;116:e108–ee12.
[29] Esses SI, Botsford DJ, Huler RJ, Rauschning W. Surgical anatomy of the sacrum. A guide for rational screw fixation. Spine (Phila Pa 1976) 1991;16(6 Suppl):S283–8.
[30] Wu A.-.M., Chen D., Chen C.-.H., et al. The technique of S2-alar-iliac screw fixation: a literature review. 2017. 2017;2(12).
[31] Zhu F, Bao HD, Yuan S, et al. Posterior second sacral alar iliac screw insertion: anatomic study in a Chinese population. Eur Spine J 2013;22(7):1683–9.
[32] Li C, Xu X, Xu J, Wei W. Safe regulable angle and optimum trajectory of the second sacral alar iliac screw: a digital simulation study. Int J Clin Exp Med 2019;12(5):5661–7.
[33] Mattei TA, Fassett DR. Combined S-1 and S-2 sacral alar-iliac screws as a salvage technique for pelvic fixation after pseudarthrosis and lumbosacropelvic instability: technical note. J Neurosurg Spine 2013;19(3):321–30.